Energy and Radionuclide Evaluation of Global Climate Model Predictions of Near-Surface Climates

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P. Irannejad[1], S. Sharmeen[1], A. Henderson-Sellers[1], T. J. Phillips[2] and K. McGuffie[3]

[1]Environment, ANSTO, PMB 1, Menai, NSW 2234, Australia
[2]PCMDI, LLNL, Livermore, CA, USA
[3]Dept. of Applied Physics, UTS, Sydney, Australia

Abstract

The near-surface continental climates of 16 Atmospheric Global Climate Models (AGCMs), participating in the Atmospheric Model Intercomparison Project II (AMIP II) are evaluated. These AGCMs incorporate land surface schemes (LSSs) with a wide range of complexity, from very simple "bucket" models to detailed soil-vegetation-atmosphere transfer schemes. The community's lack of reliable global observations for evaluating the land-surface climates is underscored, and use instead is made of three reanalyses and one global off-line land surface simulation. Compared with different observational estimates, the mean evaporation and runoff ratios over all land surfaces for the AMIP II period (1979-1995) seem to be better represented by the AGCMs than by the available reanalyses. In some AGCMs, however, the evaporation ratio is greater than unity in arid climates, and this excess of evaporation over precipitation appears to be due to incorrect initialization of soil moisture. An isotopic evaluation method for soil moisture is proposed that exploits the relationship between continental surface radon emanation rates and observed soil moisture.

In addition to various global evaluations of the AMIP II AGCM simulations, analyses of selected regions and of different climate zones, as defined by the de Martonne aridity index using climatological precipitation and observed near-surface air temperature, are presented. These analyses emphasize the partitioning of surface energy between sensible and latent heat fluxes, their spatio-temporal correlation with reference data, and their satisfaction of basic conservation laws. A small number of AGCMs and reanalyses do not conserve surface energy and water over all land surfaces: the magnitude of the imbalance varies in different regions, e.g. around the

Baltic Sea the maximum energy imbalance is about 22 W m^{-2}, while in the Amazon Basin it is about 35 W m^{-2}.

Introduction:

Simulations of surface energy components of 20 atmospheric global climate models (AGCMs) participating in Phase 2 of the Atmospheric Model Intercomparison Project (AMIP II) are evaluated. These AGCMs are coupled with land surface schemes (LSSs) with a wide range of complexity from very simple "bucket" models to detailed soil-vegetation-atmosphere transfer (SVAT) schemes.

Because of the lack of reliable global observational data sets for land-surface climates, three reanalyses (NCEP/DOE, NCEP/NCAR and ECMWF) and a global off-line simulation of the VIC land-surface scheme by Nijssen et al. (2001) are used as evaluation data sets. The possibility of using radon emanation rates for evaluating continental scale soil moisture simulation also is examined.

Analysis:

Analyses are performed globally, over selected Global Energy and Water Cycle Experiment Coordinated Enhanced Observational Period (GEWEX/CEOP) continental regions (LBA: Amazon, GCIP: Mississippi, MAGS: Mackenzie, BALTEX: Baltic), and in eight different climate zones (from arid to extremely humid, and polar), as defined by the de Martonne aridity index (I=P/T+10) using the climatological precipitation (P) and near surface air temperature (T) data of Legates and Willmott (available online at http://tao.atmos.washington.edu/data_sets/legates).

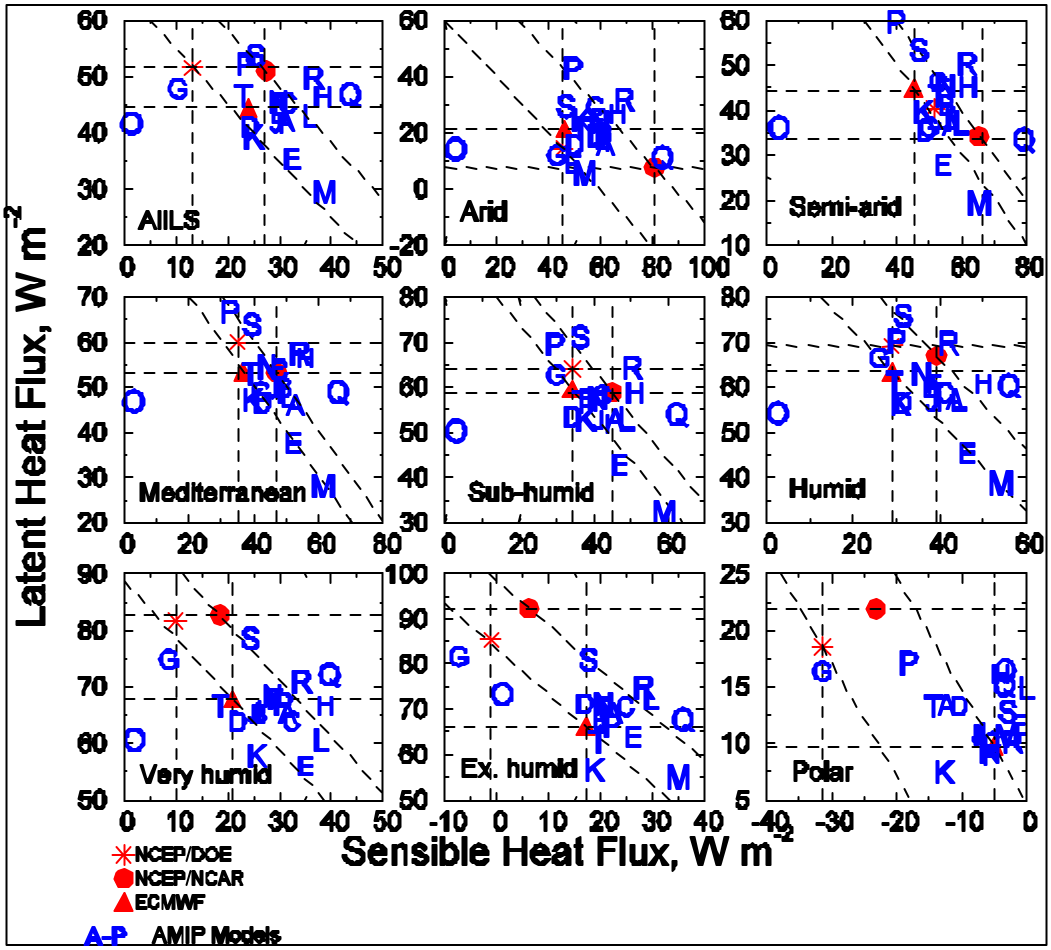
Surface Energy Balance by Climate Zone (Figure 1):

· In most climate zones the surface available energy (SAE) of a majority of AGCMs is within the range of the reanalyses (area between the diagonal lines in Figure 1),

· Globally and in more humid climates, most AGCMs overestimate sensible (SH) and underestimate latent (LH) heat fluxes, compared to the reanalyses,

· Model-simulated LH and SH agree better in arid climates.

Figure 1. Partitioning of surface available energy between mean latent (LH) and sensible (SH) heat fluxes. The dashed lines indicate the ranges of variations among the three reanalyses.

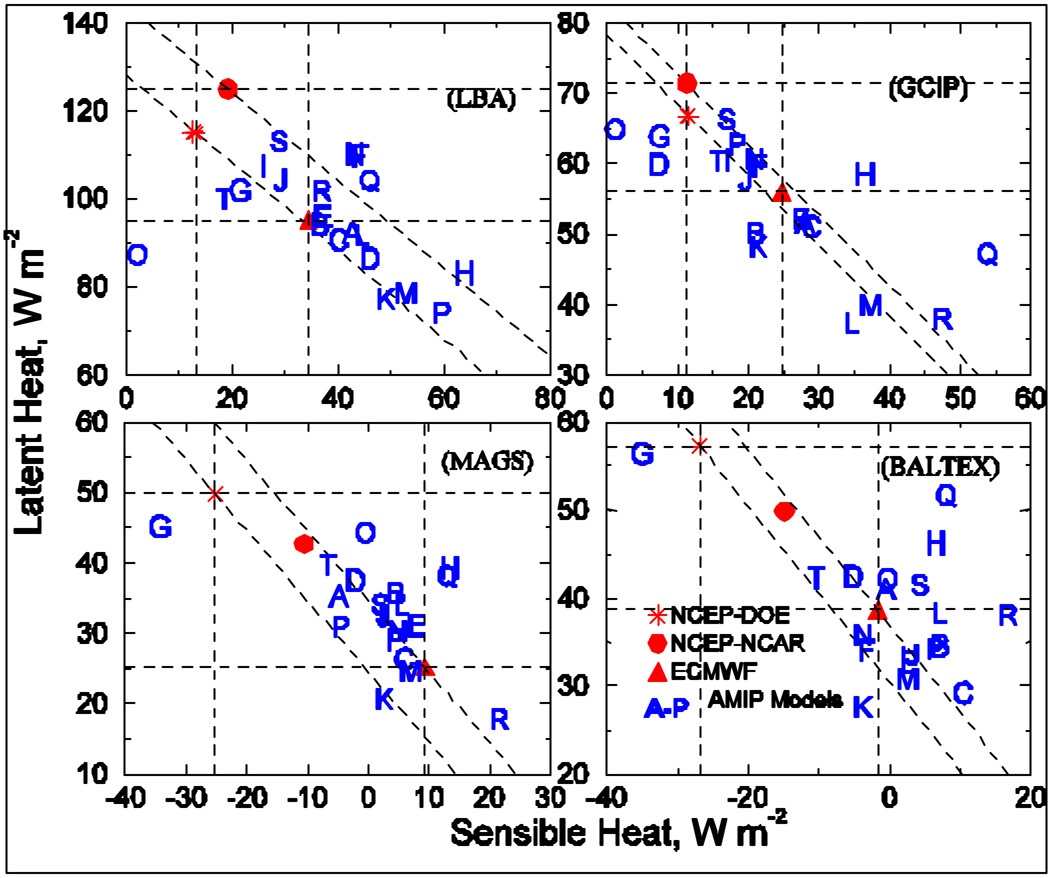


Surface Energy Balance in GEWEX/CEOP Continental Regions (Figure 2):

· AGCM-simulated continental SAE, SH and LH, compare differently to reanalyses in diverse regions (may be climate-specific),

· Most of these AGCM continental simulations agree better with the ECMWF reanalysis than with the two NCEP reanalyses.

Figure 2. Partitioning of surface available energy between mean latent and sensible heat fluxes for selected GEWEX/CEOP continental regions.

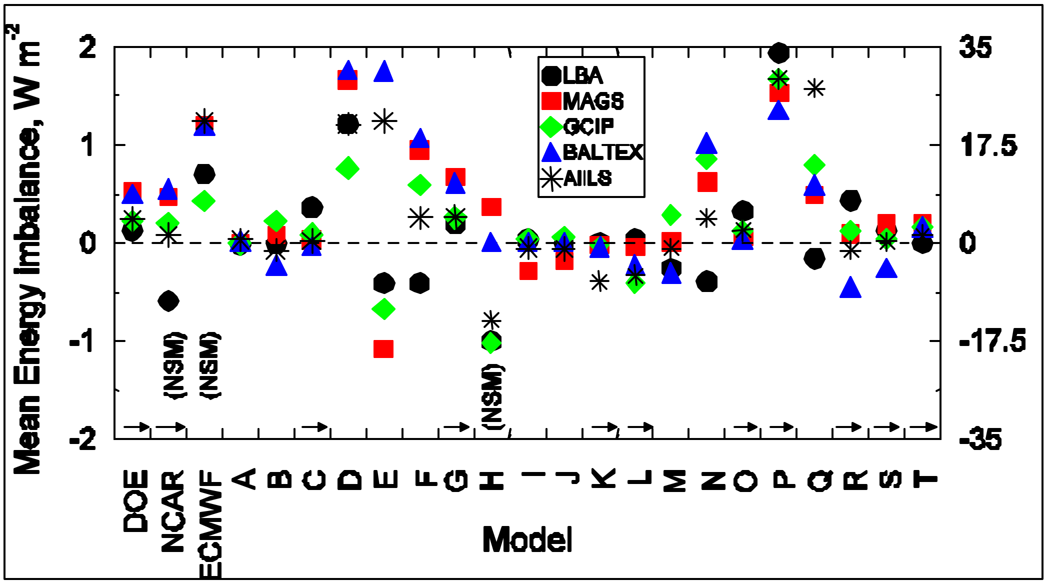


Energy Residuals (Figure 3):

· Globally, most AGCMs and the reanalyses do not seem to conserve energy (land-surfaces cooling down or warming up) over the AMIP II period,

· The magnitude of energy residual varies regionally (may be climate-specific).

Figure 3. Calculated mean energy residual of reanalyses and 20 AMIP II models globally and in selected GEWEX/CEOP continental regions for the period 1979-1995. The energy imbalance of the shaded columns is shown on the right-hand side. 'NSM' indicates instances where snow-melt heat is not included.



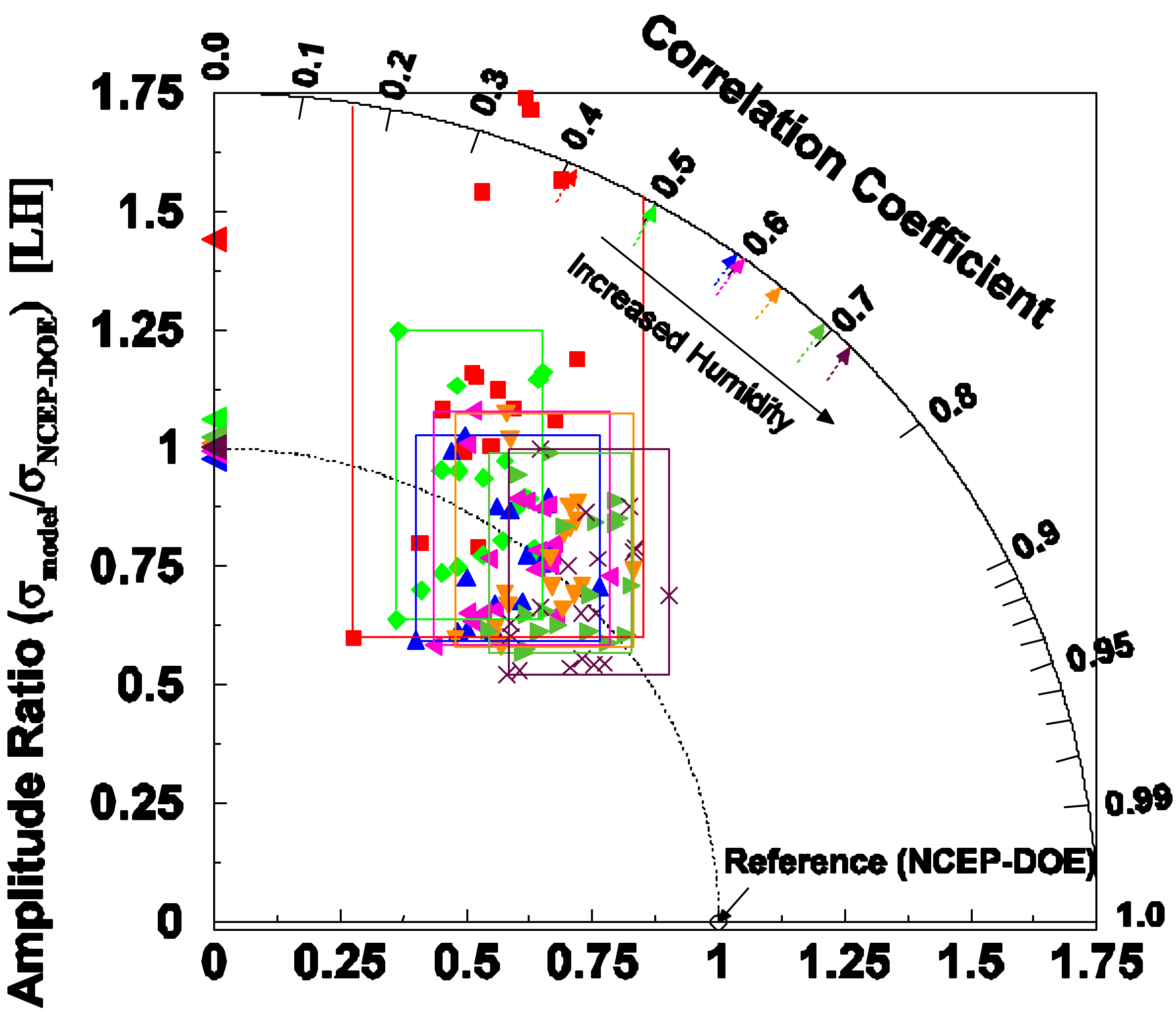
Latent Heat (LH) Flux (Figure 4):

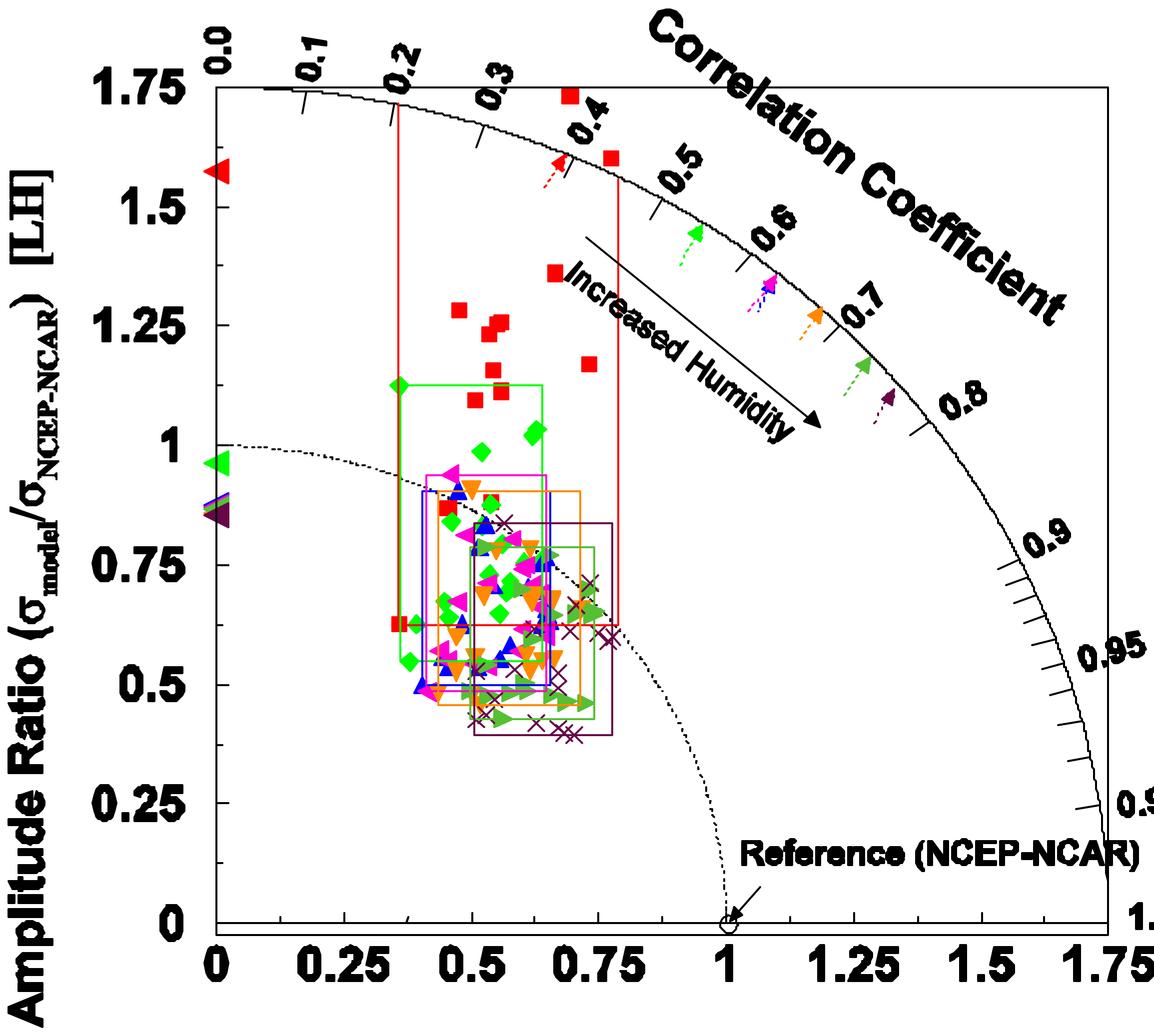
· Relative to various reference data, AGCMs perform less well in simulating LH (smaller coefficients of correlation and larger deviation of normalised standard deviation) in arid climates,

· Inter-model differences are large in arid climates,

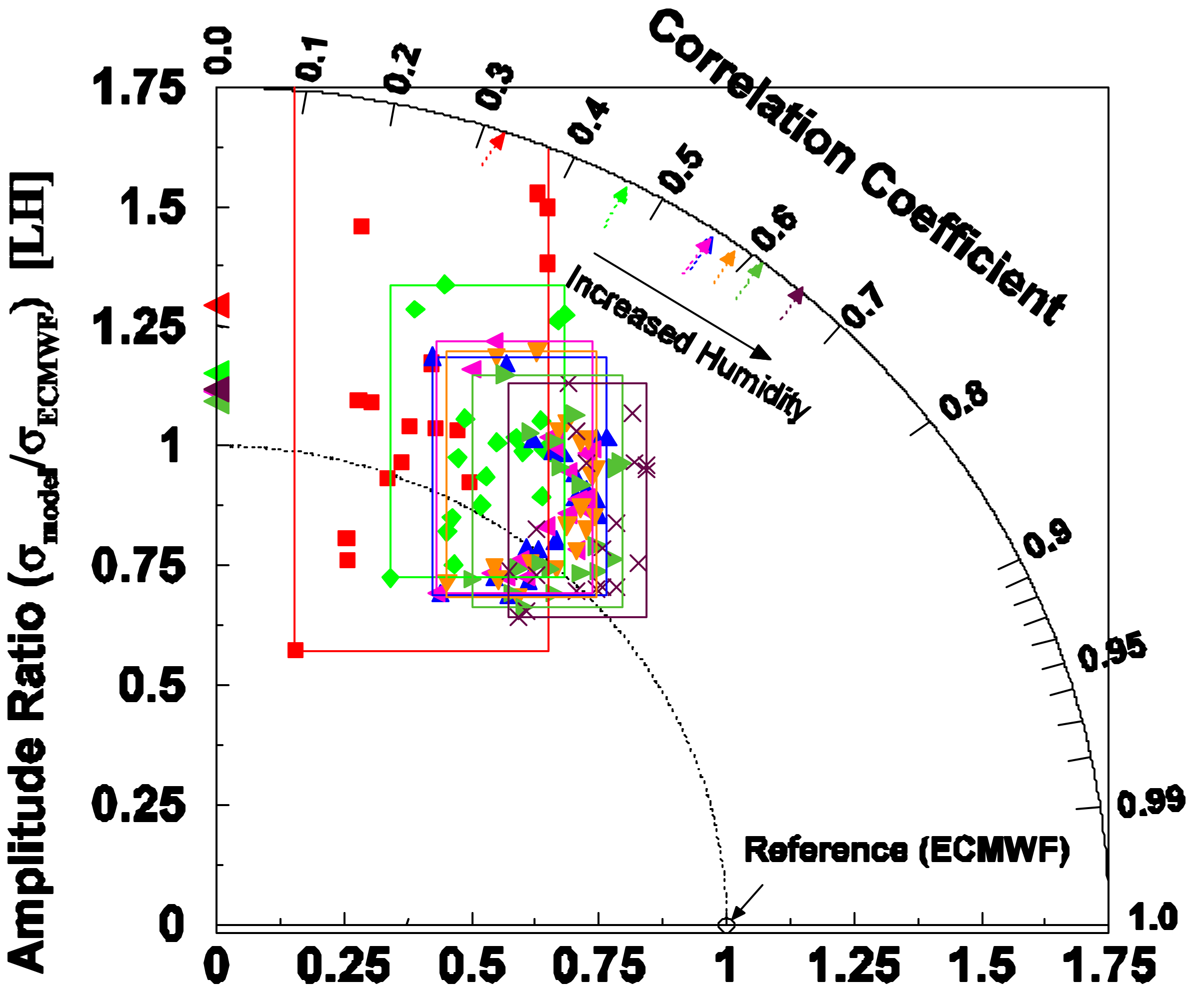
· As the climate becomes wetter, coefficients of correlation increase nonlinearly and inter-model differences decrease.

Figure 4. Taylor diagram illustrating the spatio-temporal variability of 20 AMIP II simulations, stratified by regional climate zone (indicated by similarly colored symbols, and inter-model range by rectangles), and compared against reference data sets consisting of three reanalyses and one global off-line simulation by the VIC LSS. The radial distance from the origin to each model point denotes its spatio-temporal amplitude ratio relative to the reference data, where the dotted quarter circle signifies a perfect match of standard deviations; the angular dimension is proportional to the cosine of the spatio-temporal pattern correlation; and the straight-line distance from the 'reference' is proportional to the normalised RMS error. The color-coded arrow heads situated along the vertical and angular scales are averages, respectively, of the spatio-temporal variability amplitude ratio and correlation coefficient of the 20 AMIP II simulations for the respective climate zones.

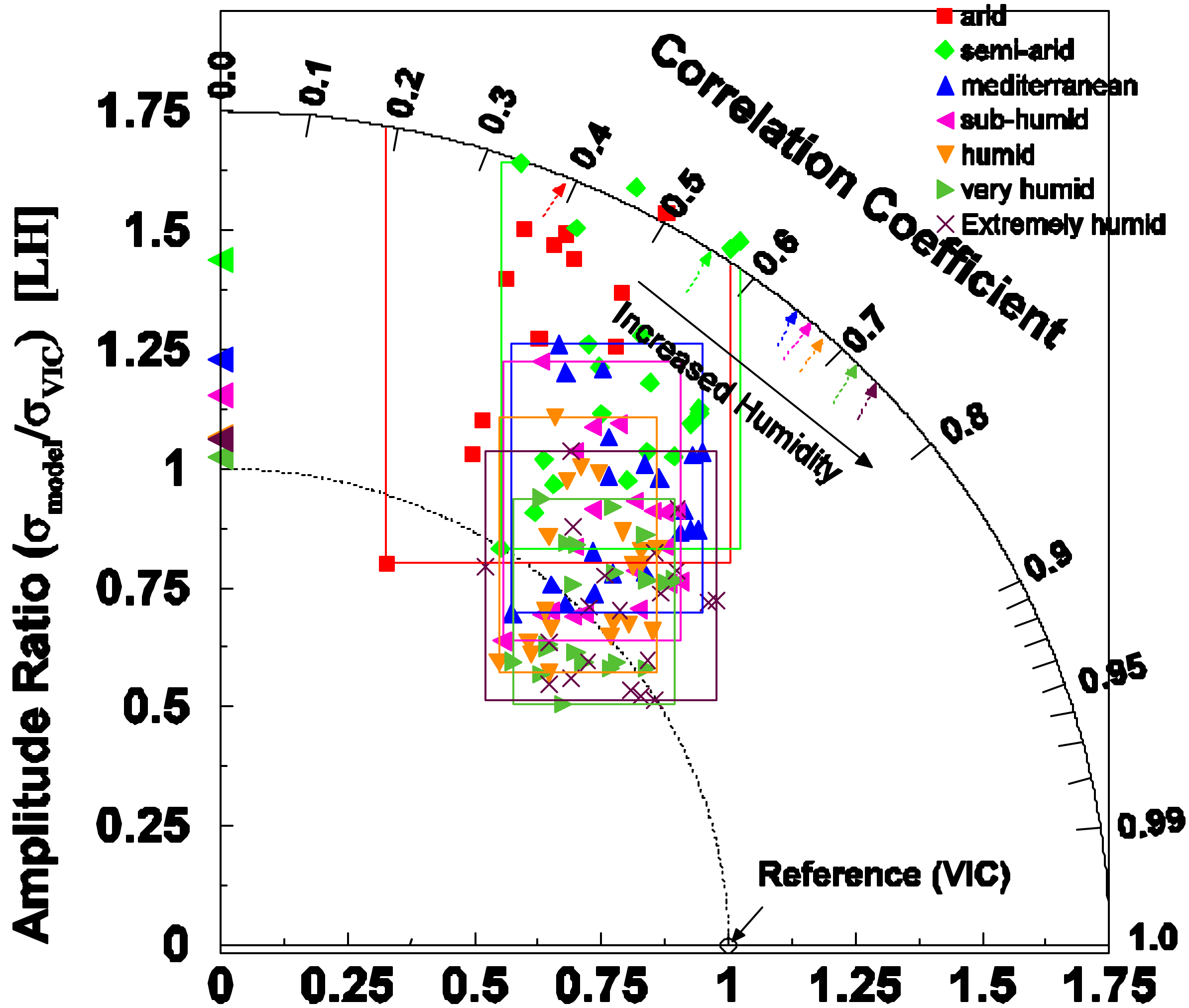




Correlation Coefficient
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
0.95
0.99
1.0
Increased Humidity
Reference (NCEP-NCAR)
Amplitude Ratio ($\sigma_{model}/\sigma_{NCEP-NCAR}$) [LH]
0
0.25
0.5
0.75
1
1.25
1.5
1.75



Correlation Coefficient
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
0.95
0.99
1.0
Increased Humidity
Amplitude Ratio ($\sigma_{model}/\sigma_{ECMWF}$) [LH]
Reference (ECMWF)
0
0.25
0.5
0.75
1
1.25
1.5
1.75



arid
semi-arid
mediterranean
sub-humid
humid
very humid
Extremely humid
Correlation Coefficient
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
0.95
0.99
1.0
Increased Humidity
Reference (VIC)
Amplitude Ratio ($\sigma_{model}/\sigma_{VIC}$) [LH]
1.75
1.5
1.25
1
0.75
0.5
0.25
0

Surface Water Balance over the Globe (Figure s 5 and 6):

· Some of the AGCMs and reanalyses do not conserve water (i.e. runoff + evaporation ratio > 1 or < 1 in Figure 5) for the AMIP II period (possibly due to model soil moisture trends or output data supplied with inconsistent units),

· Most AGCMs agree better than the reanalyses with the mean estimate (based on different observational data sets) for runoff and evaporation ratios (Figure 5),

· The evaporation ratio is greater than unity for some AGCMs especially in arid regional climate (Figure 6),

· Some, but not all, of this model behaviour is due to poor initialisation and very long spin-up period for the soil moisture (Figure 6).

Figure 5. Mean global land-surface evaporation ratio and runoff ratio, as simulated by 20 AMIP II AGCMs, and as inferred from reanalyses and from the off-line simulation of the VIC land-surface scheme forced by observed precipitation. 'Estimate' is based on the average of five different estimates of observed global stream flow and on a single estimate of global land precipitation provided by the Global Precipitation Climatology Project (GPCP) data set (Note, ECMWF reanalysis runoff is not included)

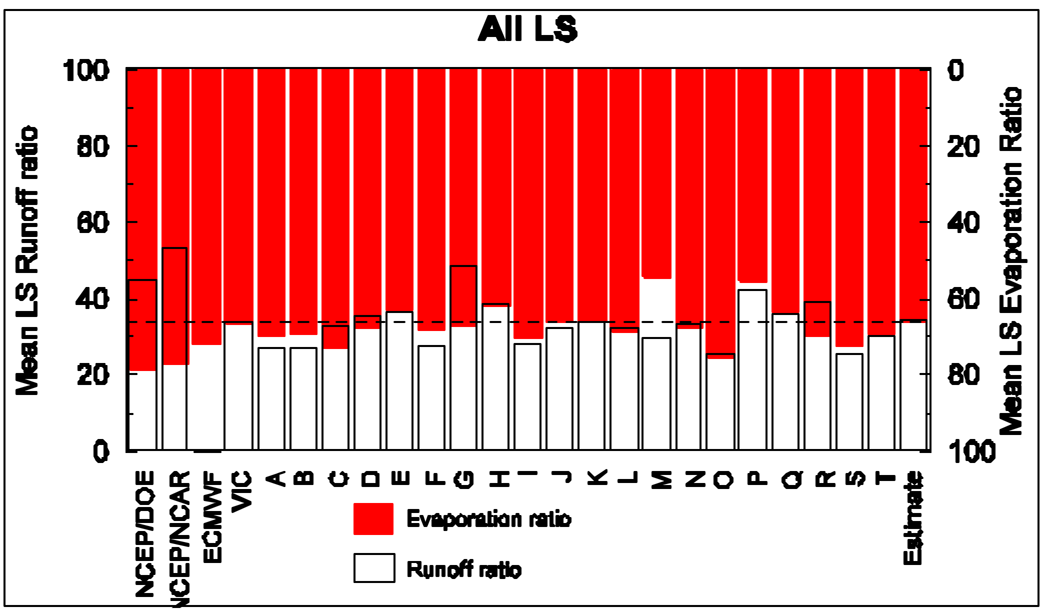
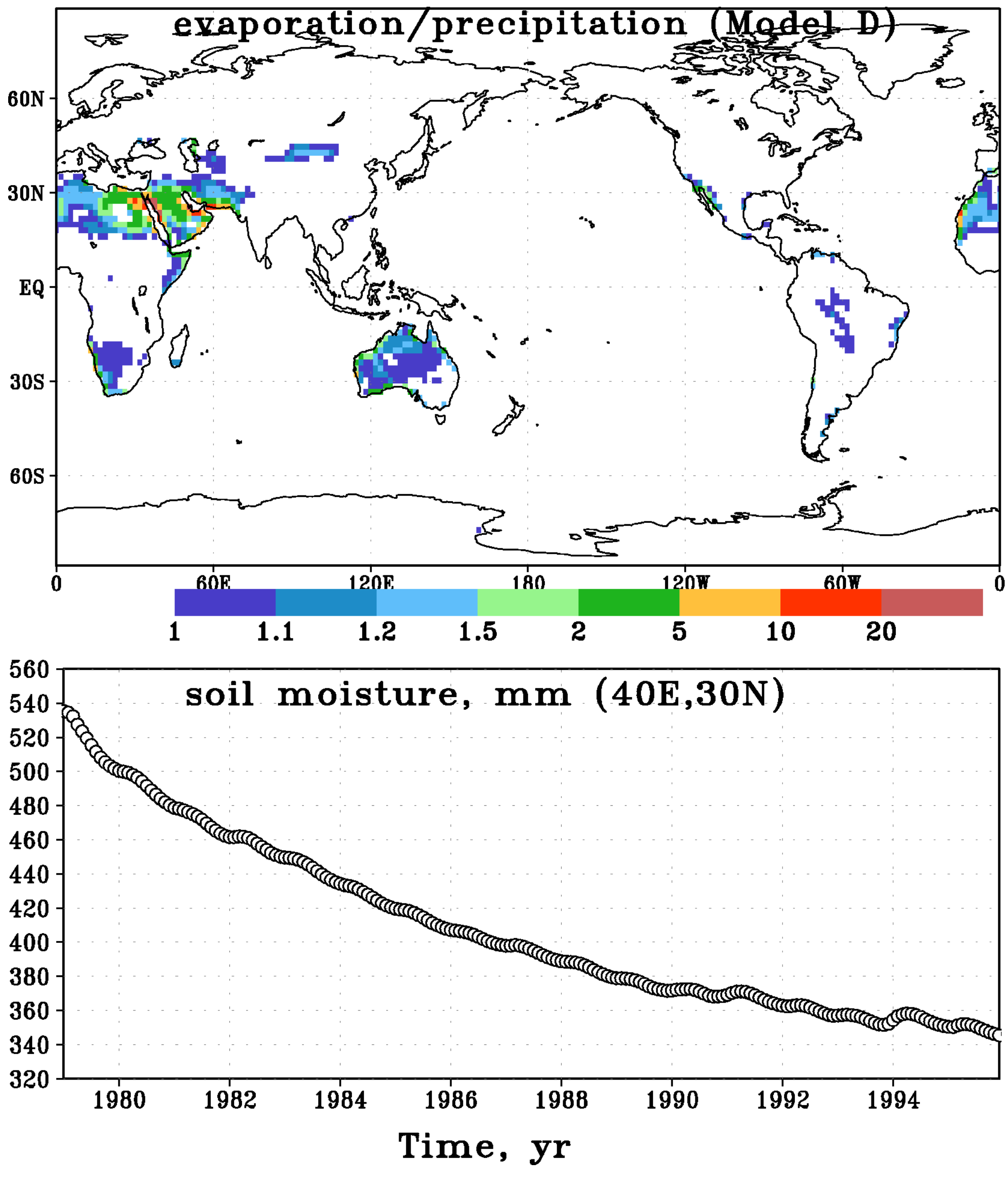


Figure 6. Evaporation ratio over land grid points for a selected AGCM (first panel). Values exceeding unity over arid and semi-arid regions are partly due to the poor initialisation and long spin-up period of the soil moisture (second panel).

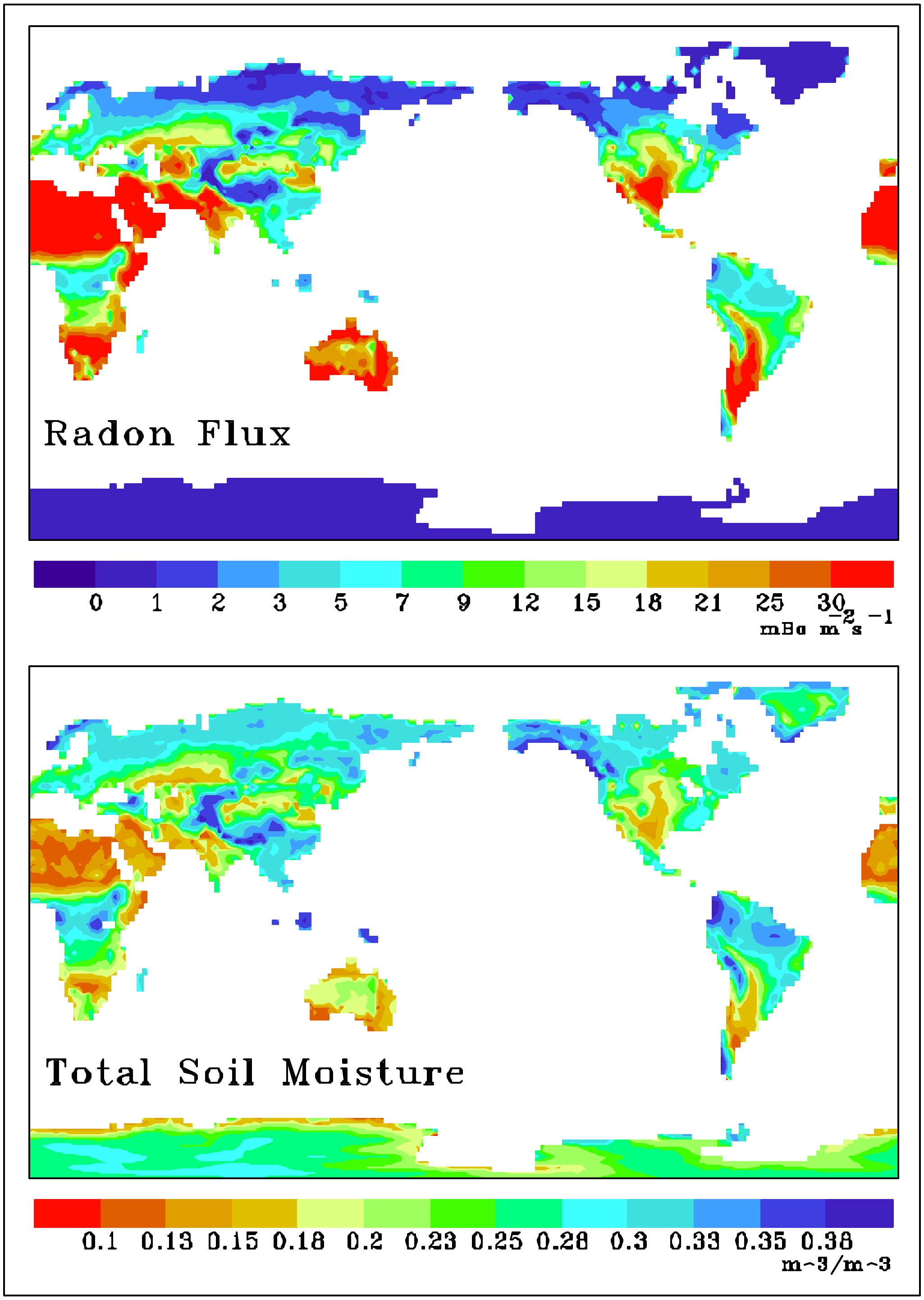


Soil Moisture and Radon Emanation (Figure 7):

· A novel method of global soil moisture estimation using radon measurements has established an additional source of AMIP II model verification,

· The spatial distribution of the calc ulated radon emanation rates and soil moisture from the NCEP/DOE reanalysis (wherein soil moisture was determined from observed, not simulated, precipitation) suggest that the radon emanation rates are large in dry regions and small in wet regions.

Figure 7. Spatial distribution of the simulated radon emanation rates compared with soil moisture from the NCEP-DOE reanalysis.



Conclusions:

· The partitioning of surface energy between sensible heat (SH) and latent heat (LH) varies for AMIP II AGCMs and reanalyses across regions and different climate zones; globally and in more humid climates most AMIP II AGCMs overestimate SH and underestimate LH, compared to the reanalyses,

· The ranges of LH and SH among the AMIP II AGCMs are at least of the same order of magnitude as those among the reanalyses,

· Some AGCMs and reanalyses do not conserve surface energy and water over land surfaces; the magnitude of the imbalance varies in different regions (may be climate-specific),

· Spatio-temporal correlation coefficients between LH of different reanalyses and AMIP II AGCMs are larger in more humid climates than in more arid climates,

· In some AGCMs the evaporation ratio exceeds unity in arid climates; this excess of evaporation over precipitation appears to be related to problematical initialisation or spin-up of soil moisture,

· A novel method of isotopic evaluation of soil moisture is established that exploits the relationship between radon emanation rates from the continental surface and observed soil moisture.

For questions or comments, please contact Parviz Irannejad (pix@ansto.gov.au)

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